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9

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9.1 Introduction

Automated functions for real world traffic scenarios have been increasing in last years in the automotive industry. Many research contributions have been done in this field. However, other problems have come to the drivers, related to the legal and liability framework, where it is still unclear up to which point the control of the vehicle should stay with the driver or be taken by automation.

The aim of the Advanced Driver Assistance Systems (ADAS) is mainly related to help drivers in safety critical situations rather than to replace them. However, in recent years, many research advances have been done in this field, making automated driving closer to reality day by day. The numbers of automated driving functions for typical traffic scenarios have increased in the last few years in the automotive industry and university research. However, other problems have appeared for drivers of such automated cars: When should the driver or the automated systems take control of the vehicle (since both cannot control an automated vehicle together at the same time due to potential conflicts)? This question has not a simple answer; it depends on different conditions, such as: the environment, driver condition, vehicle capabilities, fault tolerance, among others. Arbitration and control activities have been implemented in DESERVE WP24, mainly motivated by this question.

In this chapter, we will analyze the acceptability to the ADAS functions available in the market, and its relation with the different control actions. A survey on arbitration and control solutions in ADAS is presented. It will allow to create the basis for future development of a generic ADAS control (the lateral and longitudinal behavior), based on the integration of the application request, the driver behavior and driving conditions in the framework of the DESERVE project. Based on vehicle modeling, driver behavior and intention, a first approach for arbitration and control strategies, which can anticipate the priorities on the control in emergency situations, is described.

The main aim of this work is to allow the development of a new generation of ADAS solutions where the control could be effectively shared between the vehicle and the driver. Some simulations will allow the virtual testing for the future implementation in demonstrators.

Fuzzy logic techniques are a suitable approach for the arbitration control in the driving process. The contributions described in this chapter will be implemented in two demonstrators: Automatic/Autonomous Emergency Braking (AEB) pedestrian protection system and Driver Distraction monitoring—CRF demo vehicles—using RTMaps[1] as the development software.

The proposed arbitration and shared control takes into account the state of the driver and the state of the system, in order to assess the level of control that each system should have; based on the standard SAE J3016. Fuzzy Logic controllers consider a control level that allows a smooth control sharing between the automated system and the driver. It has been design according to the Application Platform in DESERVE control architecture. Although the Fuzzy Logic (as some other Artificial Intelligence techniques) is not explicitly considered in the road vehicles functions safety standard (ISO 26262), a large number of applications have been developed in recent years. The behavior of a human driver can be emulated with this technique.

9.2 ADAS Functions Available in the Market

Driver Assistance Systems (DAS) or Advanced Driver Assistance Systems (ADAS) can be defined as those active safety systems which require some monitoring on the vehicle's environment and on driver intentions. This extra information is combined with ego-vehicle data (positions and speed profile) in order to provide the driver with some warning or perform some automatic

[1] https://intempora.com/

actuation with the goal of increasing safety. Regarding driver interactions, a DAS can offer:

- Information about the current situation
- A warning to alert the driver
- Take the control of the vehicle, partially or completely
- A combination of them

This section is focused on those DAS which have the capability of taking vehicle control to improve or correct the driver response.

From the control point of view, control DAS systems can be classified as:

- ***Longitudinal Control Systems***: Those DAS which are able to modify vehicle speed by accelerating or braking.
- ***Lateral Control Systems***: Those DAS which are able to change vehicle direction, usually actuating on the steering system.
- ***Global Control Systems***: DAS with a combination of longitudinal and lateral control.

The Control DAS examples described in this subchapter are shown below:

Longitudinal Control Systems

- ACC (Adaptive Cruise Control)
- FCW (Frontal Collision Warning or Forward Collision Warning)
- AEB/CMbB (Automatic Emergency Braking/Collision Mitigation by Braking)
- SLA (Speed Limit Assistant)

Lateral Control Systems

- LDW/LKA (Lane Departure Warning/Lane Keeping Assistance)
- BSD/LCA (Blind Spot Detection/Lane Change Assistant)

Other Control Systems

- Pedestrian Detection/Active Hood
- Driver Distraction Detection
- PreCrash
- Parking Assistance

9.2.1 Longitudinal Control Systems

These are the main steps for the longitudinal control of the vehicle: the first system is more a comfort than a safety one (ACC), but safety systems such as

Forward Collision Warning (FCW) or AEB are built upon it. Other possibilities for Longitudinal Control of the vehicle are systems such as SLA.

ACC (Adaptive Cruise Control)

The ACC adds to the most common Cruise Control constant safety distance maintenance with the preceding vehicle. It consists of a front-mounted sensor, an integrated control unit with the task to regulate the system's performance and a suitable HMI that informs and allows the driver to control the system.

This sensor controls the area in front of the vehicle. If no obstacle is detected, the vehicle keeps the selected speed as a standard cruise control. In case a vehicle is detected in the predicted path of the vehicle (target vehicle), the sensor calculates the relative distance and speed to the target vehicle. (up to around 150–200 m). Then, the Control Unit decides whether it is necessary to actuate the brake system of the vehicle with the goal to keep a constant safety distance. When the target vehicle disappears from the detection area, the Control Unit sends the order to accelerate again until the desired cruise speed is reached.

The system works usually between 30 and 180 km/h. The maximum deceleration provided by the system is far from the maximum deceleration capabilities of the vehicle (in between 2 and 3 m/s^2)[2]. The driver can choose between different safety gaps (time – related). Developed for high capacity

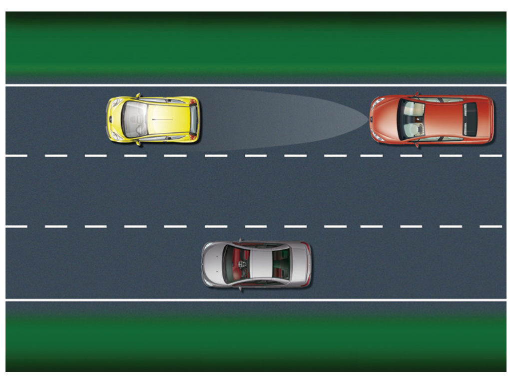

Figure 9.1 ACC Systems.

[2]In case the driver does not react, some other ACC systems are also improved with an AEB system, also considered as CMbB, providing autonomous brake action (from 5 m/s^2 to full power).

roads, ACC Stop & Go improves the performance of the conventional ACC to a full stop capability. The stop and go of the vehicle is, thus, automatically performed, so the range of the system is extended to 0–200 km/h.

FCW (Frontal Collision Warning)

When ACC fails to provide enough deceleration [exceed comfort specifications (above 2–3 m/s^2)], request to avoid a possible head-on collision, a warning, is provided to the driver (FCW). This warning reminds the driver the urge to take control of the situation. FCW is included in the basic ACC system in all vehicles equipped with the necessary sensors (laser, radar, etc.). These systems are usually activated between 5 and 2 seconds before the collision with the vehicle ahead might occur.

AEB/CMbB (Automatic Emergency Braking/Collision Mitigation by Braking)

As the third step in the longitudinal control of the vehicle, AEB is an automatic emergency safety system that takes control of the situation if the driver fails to decelerate the vehicle when a head-on collision is about to happen. The system consists on an automatic actuation of the vehicle's brakes in case the situation requires so to avoid a crash. AEB systems can be divided according to their deceleration in 1) *Soft Braking*. Up to 5 m/s^2 and 2) *Hard Braking*. From 5 m/s^2 to the full capability of the braking system.

Some systems can provide a progressive braking: first, a *soft braking* can be provided and, in case the accident seems unavoidable, a *hard braking* is applied. Also, a pre-fill of the brake circuit in case of possible risk (when the FCW system is launched) can be provided, in order to be ready for a full-brake in case it is required (either by the driver or automatically). In case the system is not able to avoid an accident but can help in the collision mitigation as the

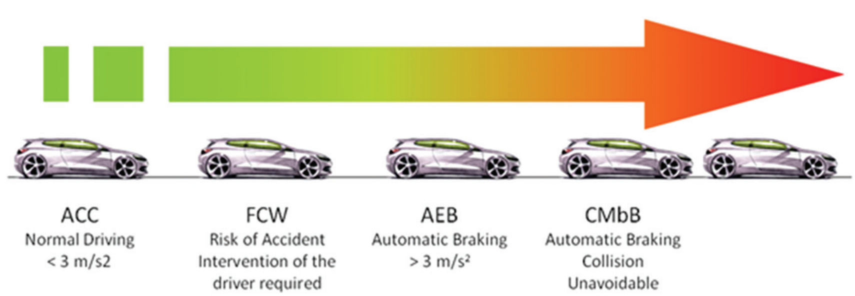

Figure 9.2 Stages on the longitudinal control of the vehicle.

obstacle is crashed at a lower speed, it is called CMbB, Collision Mitigation by Braking. The only difference is that AEB can really avoid the accident, while CMbB is launched a short time before the accident that can't be avoided any more.

SLA (Speed Limit Assistant)

The Speed Limit Assistant (SLA) is a safety system that provides the driver with information on the most suitable maximum speed continuously during his or her journey.

SLA system can be based on several sub-systems:

- TSR (Traffic Sign Recognition): Recognition of the traffic signs on the road, either by vision or gathering information from a map, is shown to the driver as a reminder of the prevailing speed limits.
- CSW (Curve Speed Warning): As extracted from the digital maps, information of the most suitable recommended maximum speed limits

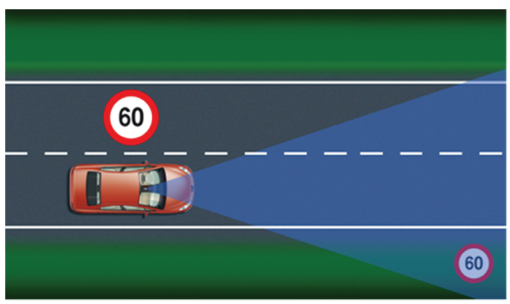

Figure 9.3 CSW system.

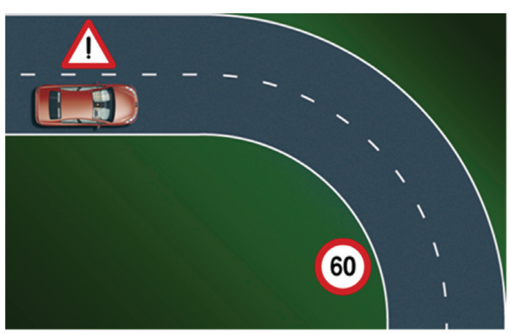

Figure 9.4 TSR system.

when passing the curve ahead are shown to the driver. Another option is to show just a warning icon in case speed is considered as too high for the incoming bend.

9.2.2 Lateral Control Systems

Lateral control systems take care of the lateral dynamics of the vehicle, either warning the driver or taking control of the vehicle actuation systems.

LDW/LKA (Lane Departure Warning/Lane Keeping Assistant)
The Lane Departure Warning system has the task to warn the driver in case he drives out of the lane due to a distraction (without using the blinkers). Many OEMs offer today a Lane Departure System under different commercial brands (AFIL, Audi Lane Assist, etc.). It is composed by a sensor (or several sensors) with the capability to detect when the driver is leaving from the chosen lane, a Control Unit and a suitable HMI for the driver.

Lane's lines detection can be done through two different technologies:

- Infrared sensors placed in the low part of the vehicle (PSA models): They use the reflection produced by the emitted light when driving over a white line to detect if the vehicle is driving over them. In this case, a Control Unit determines the driver is departing from the lane, and, depending on some other factors (blinkers, etc.), it can warn him or her by different methods (making the steering wheel or the seat vibrate, sound warning, etc.).
- Image processing: A camera—usually placed behind the windshield, on the rear view mirror housing—provides images which can be analyzed. Thus, it is possible to determine when the driver is departing from its chosen lane. This system brings advantages, such as its predictive capability (it can on obstacles in the already known driving corridor) and is more robust in front of situations such as arrows, providing considerably fewer false alarms. As a disadvantage, it can be less robust in case of poor visibility.

In any case, the system works from a certain speed (commonly, from in between 60 and 80 km/h upwards) and can be switched off. Moreover, when activating the suitable blinker, the system understands that the driver really wants to change lane and no warning is provided in case of crossing the lines.

An update of the system is also found in the market: LKA (Lane Keeping Assistant), which includes an additional torque on the steering wheel (electrical

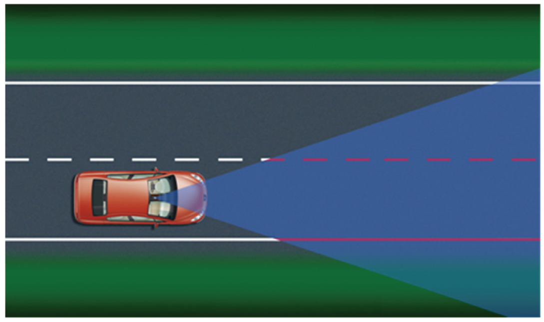

Figure 9.5 LDW system.

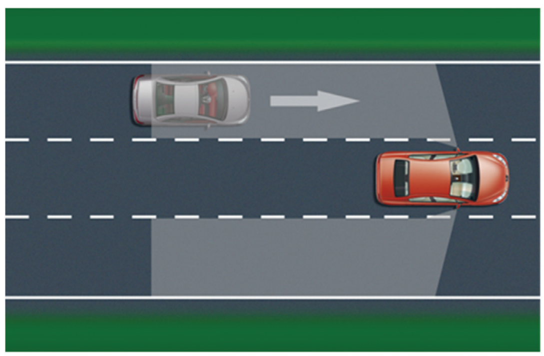

Figure 9.6 BSD/LCA system.

power steering is required) that helps the driver to keep the vehicle into the desired lane.

BSD (Blind Spot Detection)

A Blind Spot Detection system has the goal to warn the driver in case another vehicle is located in the blind spot which is not controlled by the rear-view mirrors.

Therefore, it counts on some sensors (commonly, short range radars @ 24 GHz or image processing units) which monitor constantly the area placed in the lateral blind spots of the vehicle. These sensors provide information to a Control Unit, which decides the susceptibility to provide the driver with a warning. This warning can be acoustic, visual or haptic.

Some systems can warn continuously on the existence of objects in the blind spot. Some others only warn when the driver expresses his or her will to change lane, using the correspondent blinker. They usually work over a certain speed and are capable to exclude parked vehicles or those driving in the opposite direction, in order to reduce the false alarm rate. The detection area can measure around 10 meters behind the rear view mirror and 4 meters wide, enough to cover the blind spot.

LCA (Lane Change Assistant)

A Lane Change Assistant is a system which increases the possibilities of a Blind Spot Detection System. The detection distance can achieve up to 50–60 meters behind the ego-vehicle (positions and speed profile of the vehicle) in the adjacent lanes. Moreover, the relative speed of the detected vehicles is also taken into account, so the system is capable to warn the driver in case the lane change is too risky because of a fast approaching vehicle from behind. Depending on some parameters, different warning levels can be included.

9.2.3 Other Control Systems

Pedestrian detection/Active hood

A pedestrian detection system is capable to recognize a potential danger. In this case, the driver can be warned or even an automatic action can be performed (automatic speed adaptation). In case of unavoidable crash, the activation of passive safety measures is also considered (active hood).

PreCrash systems

In the transition or overlap between active and passive safety, PreCrash systems work when accidents are unavoidable. Its mission is, based on the information gathered by the rest of the safety systems, and after determining the accident cannot be avoided by its intervention, to prepare the passive safety elements of the vehicle to better perform their safety mission. For instance, when there's a sure head-on collision, CMbB will reduce the speed of the crash, while PreCrash will pre-tension the seatbelts, will move the seats to place them in a more convenient position or will pre-trigger airbag deployment order. PreCrash systems can cover the front of the vehicle, the rear or all 360° of the vehicle.

Parking assistance

Parking assistance is one of the most implemented DAS. There are many types of technology used on this. This section will not be focused on the traditional ultrasonic or vision aided parking assistance systems, but on the systems that can provide some kind of support to the driver. These systems can be divided in the following ones:

- *Vision-Aided Systems*: together with the image of a camera placed in the rear part of the vehicle, some support provided by visual guidelines in the dashboard display.
- *Top View Systems*: up to 4 cameras placed on exposed surfaces around the vehicle provide images that, after some processing, can be shown on the vehicle's display as if it was seen from above.
- *Aided Park Systems*: some systems can provide support to the driver on his/her search for parking spots or his/her maneuvers to park the vehicle.

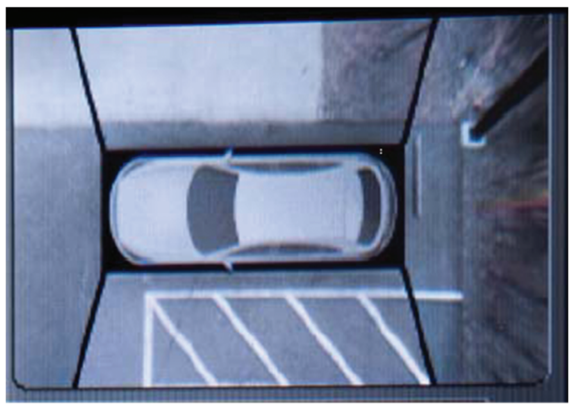

Figure 9.7 Top view of a parking assistance system.

Figure 9.8 Aided park system.

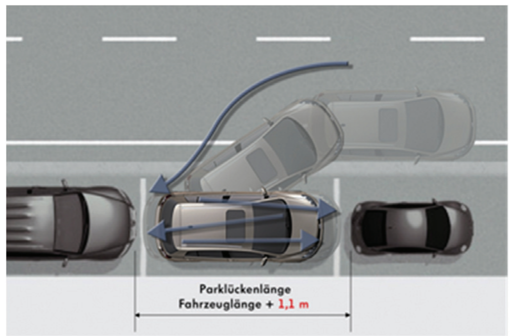

Figure 9.9 Automatic park systems.

- *Automatic Park System*: this system can take control of the steering of the vehicle in order to park automatically after detection of a parking slot. The driver remains responsible for the longitudinal control of the vehicle.

9.2.4 Control Solution in ADAS

Based on most control architectures for Automated and semi-automated vehicles [2], DESERVE is divided in three main platform parts or stages: perception, application and information-warning-intervention (IWI). The sensing and perception of environmental and onboard information is vitally important for any automotive DAS function. Based on preliminary work from other funding projects in this area[3] the information flow and architectural decomposition of the DESERVE platform is shown in Figure 9.10.

The three main building blocks in Figure 9.10 are the perception layer, the application layer and the IWI controller layer. The same decomposition was also chosen from other parties in similar projects (like InteractIVe [3]) and corresponds to the naturalistic behavior that is applied when accomplishing a given task, namely the action points “sense”, “plan” and “act”. As baseline DESERVE considers the results of several research projects, like InteractIVe, but targets the standardization of the software architecture.

Indeed, by handling the sensor and actuator information on a virtual and abstract level, a systematical standardization of input and output interfaces can be realized. This results both in a very good encapsulated module architecture and makes exchange or addition of further module components much easier.

[3]InteractIVe—FP7/ICT funding project—www.interactIVe-ip.eu

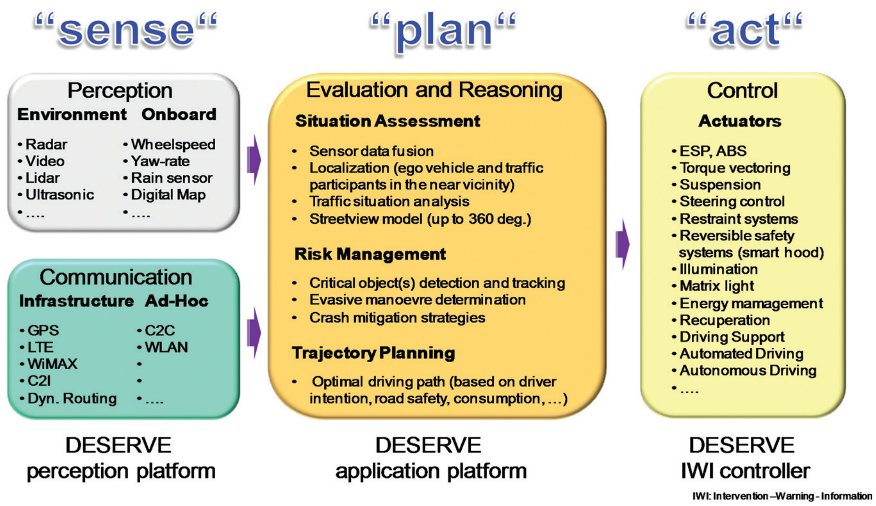

Figure 9.10 DESERVE platform.

In particular, the Perception Platform processes the data received from the sensors that are available on the ego vehicle and sends them to the Application Platform. The data received from the Application Platform are used to develop control functions and to decide the actuation strategies. Finally, the output is sent to the IWI Platform informing the driver in case of warning conditions and activating the systems related to the longitudinal and/or lateral dynamics.

9.2.4.1 Perception platform

The main objective of the Perception layer is to define and develop the DESERVE platform components that will interface with sensors and actuators, acquiring information from the typical sources. All these possible information sources are addressed, described and characterized in an abstract level that allows virtualization of input and output data. By using such an abstract and virtual intermediate layer the connection/exchange of sensors or actuators and the porting or adaptation to different vehicle models is expected to become much easier and less time consuming.

The DESERVE Perception layer is composed of different sub-layers that build up, in their totality, the complete information source that can be imported into the DESERVE platform framework. In a generalized sense the Perception layer can be seen as the input and output (I/O) gateway, especially when including communication devices and the different actuators as part of the I/O components.

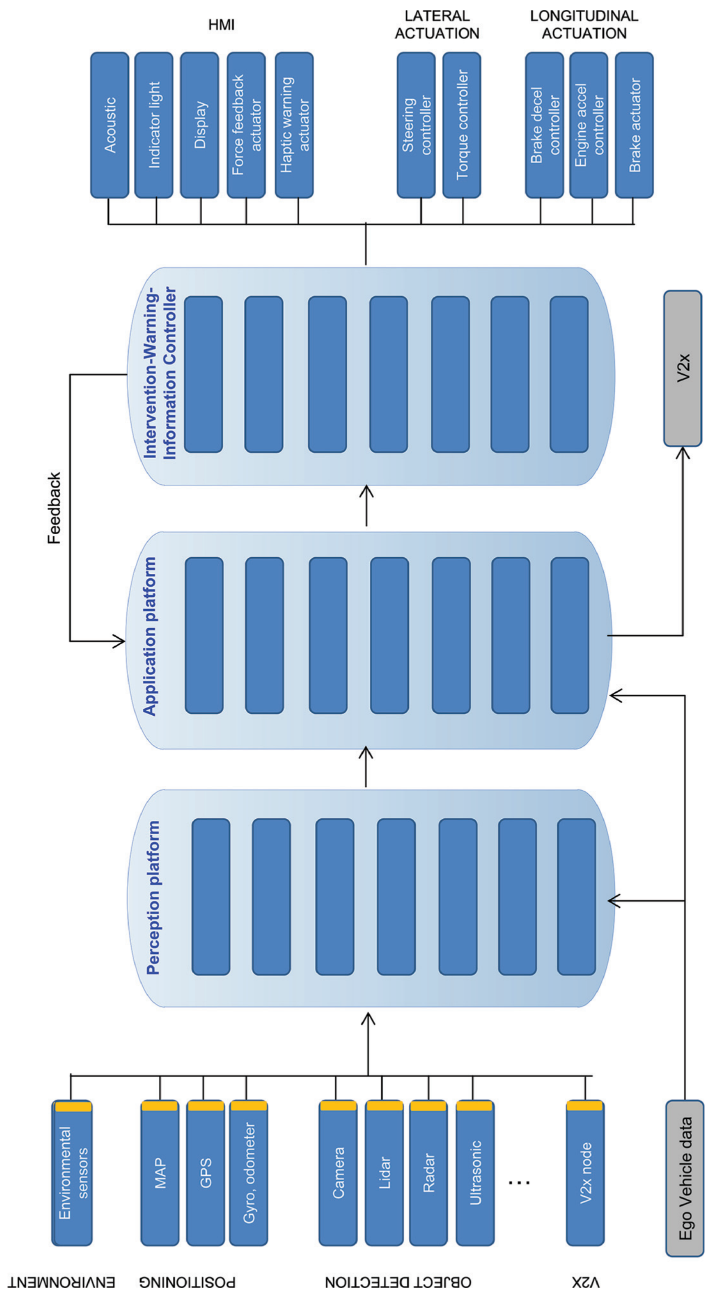

Figure 9.11 DESERVE platform framework.

9.2.4.2 Application platform

Based on these assumptions and previous works, a control strategy for sharing vehicle control between the driver and embedded ADAS systems was proposed. These layers can be used dynamically, based on the information from the driver monitoring automotive—DMA.

Since the driver is legally responsible for operating the car in its environment, in our approach he/she will have the last responsibility in the arbitration control process. However, if the driver is not enabled to drive, then the control will be taken by the embedded system.

The specific Application modules used in the arbitration and control of the vehicle are:

- Threat assessment: the information from Frontal Object Perception, Vehicle trajectory and Driver intention modules will be considered, in order to establish a risk level in each scenario.
- IWI manager: this module will determine the action to be taken by the driver or the vehicle (here we can set the Arbitration and Control functions). The Driver Assistance Systems involve two main decision makers: when is the driver who takes the control or when does the automated system and up to which extent.
- Vehicle control: Only the brake pedal will be considered. Classical control techniques considering comfortable/safe accelerations. Longitudinal control based on PID and Fuzzy logic controllers have been used in automated functions.

The level of assistance provided by the automated car to the driver might change depending on the driver's state and on the situation at hand (imminence of danger). With a varying level of automation of the automated vehicle, control might smoothly flow from the driver to the automated car and vice versa.

9.2.4.3 Information Warning Intervention (IWI) platform

The Information Warning and Intervention module uses the output of the Application layer and provides ways to execute the interaction with the driver and the control of the vehicle. Mainly the information is sent to the actuators that will translate high level commands into acceleration and steering angle to provide the correct answer expected from the vehicle.

In a similar way, information is sent through the HMI towards the driver if necessary. These messages will warn and inform the driver (visual and acoustic signals/messages), as well as interact with him/her (haptic signals).

In order for these messages to be effective, great efforts have been done in HMI solutions where the current hot topic is to share the control with the driver. In the following, a review of some techniques for the arbitration and shared control are presented.

9.3 Survey on Arbitration and Control Solutions in ADAS

In the transportation field, human machine interaction plays a key role. Nowadays, significant results have been achieved in the automated driving field (at least, under certain circumstances) [4, 5]. Nonetheless, there is a long way to go before removing the driver from the loop in real traffic conditions.

Parasuraman et al. [7], stated that the main problem in this kind of systems lies in the decision making process and the assignment of control responsibility. In the ITS field, shared control is the action of carrying a task simultaneously between a (on board) computer and a driver, differing from manual control and fully automation (since no real "sharing" is being done in this situations, see Figure 9.12).

The first levels of automation were set by Sheridan in [9]. Here, 10 different levels described the amount of responsibility for each decision maker. Flemisch et al. in [10] presents a more developed view of the levels needed for control sharing, where the automation is based in the H-metaphor and clarified in two main groups: Tight rein and loose rein.

Recently [11], new taxonomy of automated driving was issued by SAE International; its control levels are depicted by Figure 9.12. Other levels of automation have already been proposed by the German Federal Highway Research Institute (BASt) [12] and the National Highway Traffic Safety Administration (NHTSA) [13]. A comparison of these is summarized in [11], stating that the SAE taxonomy is alike the other two, but gives a broader and more specified view of automation levels. For this reason, the SAE taxonomy will be the one taken into account (see Figure 9.12).

When considering the driver in the control loop, it is important to know the automation level embedded in the vehicle. This will permit the control

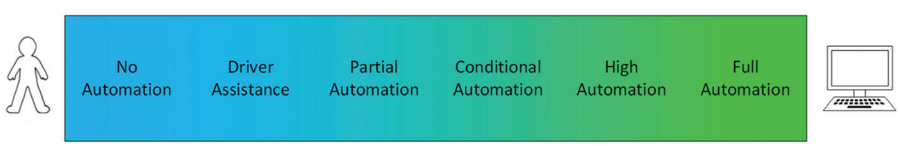

Figure 9.12 SAE J3016 standards of driving automation levels for on-road vehicles.

sharing system to set the limits for each decision maker. We will deepen in the arbitration concept as a way to change, in a smooth way, the level of control according to the situation in-hand.

The **Arbitration concept** is *the process of settling an argument or a disagreement by an entity that is not involved*.[4] Little research has been done in terms of arbitration (since it is a new concept in vehicle automation). First approaches define cognitive states and relations between humans and machines [6], also mental models as in human relationships have been considered by [14]. This consideration leads to a scenario where the status of the driver and the system must be known, at all times, aiming to set an accurate level of automation for the current situation.

From the above, communication between the system and the driver should constantly occur, in a way that is possible for both to make a mental model of one another [14]. Also different metaphors have been stated, such as the copilot metaphor (referring to the automated system) and the H-metaphor as a comparison between horse-human cooperation and vehicle-human cooperation [15].

9.4 Human-Vehicle Interaction

Increasing need to pay more attention to the human driver in interaction with the vehicle has been recently identified [1]. From other domains where automation is already widely used (e.g. aviation, central rooms) it is known that automation has both positive and negative effects on the human operator. With increasing automation in the vehicle domain these effects need to get far more attention on the short term, evaluating the human-vehicle relationship and assigning countermeasures if necessary [1]. In order to have a regular communication between the two decision makers (the driver and the embedded system), in [15], a haptic HMI system is proposed where active force feedback is the common language. This allows the message to be directly linked to the actuator where the reaction of the driver is expected, also allowing the system to evaluate the performance of the driver. The haptic feedback can also give hints in terms of the action the driver should perform (e.g. the steering wheel turns a little to the right or left in order to hint the driver).

Haptic systems have been implemented widely across the literature: in gas pedal feedback [16, 17], and in steering wheel feedback [18, 19]. These are also used in training simulators, improving the performance of drivers in different scenarios.

[4] Oxford dictionary.

The use of corrective feedbacks is known to cause over-corrective behavior [8] or bad performance when removed. This happens because it impairs the input-output relationship in motor skill learning of the driver. In [20], the haptic aid shows a good performance if the feedback is provided as needed and not all the time.

For arbitration and shared control, a state of the driver is needed in order to know his current status to perform the driving task. In [21], an extensive study on driver distraction was performed. It showed that in terms of visual and cognitive attention sharing, while performing following or passing driving maneuvers, a warning from the HMI proved to be helpful.

In [22], the importance of vision at the driving task was stated. Although visual acuity proved to be important, other indicators of the driver ability (Visual field, processing speed, divided attention, among others) have evidence-basis for their relevance to the driver ability and safety, and can be measured in a noninvasive way with recent in-car perception systems, as in [23].

Recently, the HAVEit[5] project [24, 25], and the InteractIVe[6] project [26] have made the first approaches into control sharing strategies, theoretically and in simulations, with driver-in-the-loop capabilities.

The aim of arbitration and control solutions in ADAS, inside the DESERVE project is to effectively share the control with the driver and manage risky situations. In [27], ADAS applications are listed such as lane change assistance systems, pedestrian safety systems, adaptive light control, and parking assistance systems, among others. These are considered to improve the automated system and take into account the driver-in-the-loop for arbitration applications [28].

Arbitration systems for shared control applications is a new concept in the ITS research field. Based on previous contributions, it is the objective to develop a system able to share the control—in a smooth way—between the decision makers. Motivation for this approach can be found in social needs [29], legal challenges [1, 33] and technical bases such as the DESERVE platform (see [11]).

9.5 Driver Monitoring

Driver's limitations are very often related to his physiological and psychological states. An optimum pilot state includes an optimum alertness level

[5] http://haveit-eu.org/
[6] http://www.interactive-ip.eu/

and a task-oriented attentiveness. The distinction between "alertness" and "attention" is justified in the way that driver "alertness" is presumed to be necessary but not sufficient for an appropriate focus on external events. Thus, drivers may be alert but still be inattentive. In order to assess alertness and attentiveness in the DESERVE project, two main factors are evaluated:

- Drowsiness/fatigue
- Distraction

Up to now, a universally valid definition of drowsiness still lacks. A tired driver mainly derives from performing a highly demanding task for extensive time periods ("time-on task" for the driving effort). Other definitions focus on the sleepiness level, which is the state of being ready to fall asleep. It is mainly caused by circadian rhythms and sleep disorders (reduced quality or quantity of sleep).

On the other hand, *"Driver distraction refers to those instances when a driver's attention is diverted from the primary task of driving the vehicle in a way that compromises safe driving performance"*, [30]. This distraction can be either internal (e.g. other passengers interaction, cellphone, etc.) or external (e.g. other road users, traffic signs, etc.). It can also be classified in different modes as: Visual (external attractors for example advertisement on the side of the road or internal attractors e.g. looking to his children at the back of the vehicle, displaying an address onto a navigation device, etc.), acoustic (ringing phone, listening music) or cognitive distraction (conversing at phone but also internal thought and rumination, etc.).

For more information about on-line driver monitoring approaches, the reader is referred to [34]. Here a description of the different on-the-market and research methods and approaches are described in detail. In the DESERVE project, two main approaches were taken into consideration for the assessment of alertness and attentiveness of the driver:

The Continental driver supervision system is implemented for a real time monitoring of two independent parameters, the drowsiness level (sleepiness vs. awakeness) and the visual inattention (e.g. the driver "is/is not" looking to the road) [23].

The Driver state monitoring includes a compact low consumption and high dynamic range (120 dB) CMOS camera sensor. The camera is equipped with a global shutter for the synchronization with a set of pulsed NIR lights (850 nm).

Ficosa's Somnoalert Sensor aims to detect "non-apt to drive" states using physiological signals such as thoracic effort signal. An external thoracic effort sensor sends the signals to a smartphone, where it is processed to evaluate the state of the driver and indicate if this becomes dangerous.

9.5.1 Legal and Liability Aspects

For automated vehicles, it is still unclear how legal and liability aspects are going to evolve. As a matter of fact, the U.S. legislation does not prohibit nor allows the use of automation in the driving task [31]. This leaves an important legal gap towards the responsibility of any action taken by the on-board system, since it is now an entity that "thinks for itself". Similar situations arise in Europe where in a crash the responsible at all times is the driver, even when an embedded system was controlling the vehicle [32].

From the legal perspective, several initiatives in the U.S., specifically in the states of Nevada (2011), Florida (2012), California (2012), Washington D.C. (2012) and Michigan (2014), have already established some of the minimum safety requirements in order to allow automated vehicles technology [33]. Other state legislations in the U.S. are following these initiatives, to take a wider view of this the reader is referred to [32] and [33]. In the E.U., initiatives launched between governments and manufactures are currently creating the framework for the new standards and regulations for automated driving. These address legal matters and promote the standardization of the automated vehicles technology, as for example the Citymobil2 project [36].

As to liability, Beiker and Calo [35] noted that the situation is more complex with automated vehicles, concluding that it is unclear how the courts, or the public, will respond to the prospect of artificial intelligence acting on behalf of humans with fatal consequences. They expect that a set of policies can be established to create the necessary legal framework for further development of vehicle automation. In the E.U., the legal framework sets the liability of any crash towards the driver. This creates many barriers for automated vehicles and restricts them to private roads.

As a matter of fact, automation (or the lack of it) is not black or white but rather in shades of gray, complex and involving many design dimensions [1]. OEMs are careful with this and do not claim that an ADAS is working in all driving situations. A helpful model of automation is to consider different levels of assistance and automation that can e.g. be organized on a scale as in [11]. This not only suggests but encourages the use of systems that consider the driver-in-the-loop. These systems will allow the industry to add driver's vigilance to their system's supervision and avoid gaps (at least in the legal framework).

9.6 Sharing and Arbitration Strategies: DESERVE Approach

The arbitration module is defined in the information, warning, intervention (IWI) manager (Application platform) of the DESERVE abstraction layer (Figure 9.11). This Advanced Driver Assistance System involves two main decision makers: the driver and the automated system. It will determine the level of responsibility of each of them at all times and allow smooth transitions between automation levels defined in [11].

Based on the information from different perception systems, it is possible to define fuzzy control parameters to achieve this, as was proposed in [37, 38]. This cognitive process will result in the selection of a course of action among several alternative scenarios (e.g., up to which amount the driver should be responsible of the pedal action in an ACC maneuver while tired). The proposed system consists of a two level fuzzy approach for the arbitration (IWI manager) and vehicle sharing (VMC) modules.

The arbitration and sharing control concept has been developed in RTMaps, one of the development platform defined in DESERVE. Figure 9.13 shows the general diagram for the arbitration. Here a fuzzy logic approach is implemented to compute the automation assessment (or situation status of decision-makers). This value is an assessment of the alertness and attentiveness of the driver w.r.t. the risk detected from the situation status.

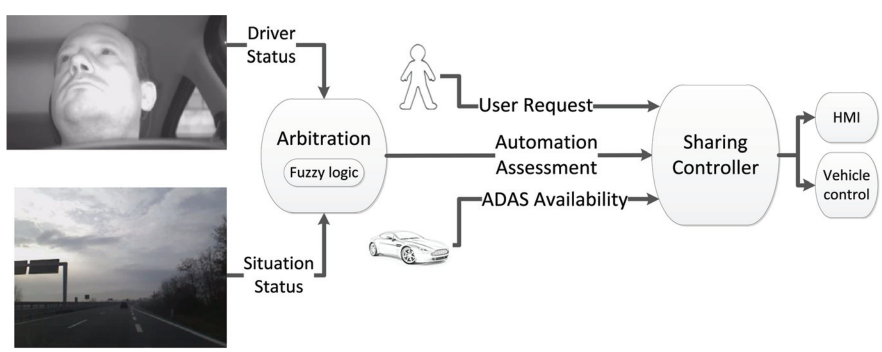

Figure 9.13 Arbitration and control sharing application: General diagram.

The sharing controller considers the automation assessment (but also the driver and the automated systems decisions) to decide the level of control and responsibility of each decision maker in real time. The output goes then to the HMI, informing the driver (a haptic steering wheel system informs the driver of next maneuvers that the system is ready to perform), and to the vehicle control. This process is done in real time, allowing a smooth sharing between decision-makers. For details and further perspective in first preliminary results please refer to [38].

9.7 Conclusions

This chapter presents a survey on arbitration and control solutions for ADAS, based on the ADAS solutions available in the market, and the ones considered from the functional requirements described in Sub-Project-1 of the DESERVE project. The main architecture is described as a three-pillar platform system first “sensing” the environment, then “planning” according to decisions made over perception data and finally “acting” to follow those decisions.

For the sharing and arbitration approach, different points of view have been considered. Here, the estimation of the driver state and the assessment of the risk related to the situation in hand are the most important ones. These allow the system to have a coherent evaluation of the situation of both decision makers and arbitrate if the vehicle’s embedded system needs to intervene because of risky driver actions.

This intervention is performed through haptic signals. However, there are still some challenges with respect to HMI solutions that can properly work as a communication bridge for the two decision makers and inform the driver—on time—of automated vehicles decisions.

Furthermore, legal and liability aspects are important milestones yet to be tackled. Although some states of the U.S. are taking the initiative, law regarding automated vehicles is in its first steps. Liability and legal responsibility still lies with the driver, hence, in our approach the control lies with the drivers (the driver can deactivate the system at any stage and is stronger than haptic cues). In future research we will focus in the arbitration, to determine (using some perception information) up to which point the embedded system can take control of the vehicle and which situations are more dangerous (risk management, taking special care of situations where overreliance on the system occurs—the embedded system returns the control to the human driver).

References

[1] Schijndel-de Nooij, Margriet, Krosse, Bastiaan, Broek, Thijs, Sander Maas, Ellen van Nunen, and Han Zwijnenberg. "*Definition of necessary vehicle and infrastructure systems for Automated Driving*", Study Report for the European Commission (2011).

[2] González David, Pérez Joshué, Milanés Vicente and Nashashibi, Fawzi., "*A Review of Motion Planning Techniques for Automated Vehicles,*" in Intelligent Transportation Systems, IEEE Transactions on, in press.

[3] Hesse, Tobias, et al. *Towards user-centred development of integrated information, warning, and intervention strategies for multiple ADAS in the EU project interactive.* s.l.: Universal Access in Human-Computer Interaction. Context Diversity, 2011.

[4] Ziegler, Jens, Philipp Bender, Markus Schreiber, Henning Lategahn, Tobias Strauss, Christoph Stiller, Thao Dang et al. "*Making bertha drive—An autonomous journey on a historic route.*" Intelligent Transportation Systems Magazine, IEEE 6, no. 2 (2014): 8–20.

[5] Broggi, Alberto, Pietro Cerri, Stefano Debattisti, Maria Chiara Laghi, Paolo Medici, Matteo Panciroli, and Antonio Prioletti. "PROUD-Public road urban driverless test: Architecture and results." In *Intelligent Vehicles Symposium Proceedings, 2014 IEEE*, pp. 648–654. IEEE, 2014.

[6] Hoc, Jean-Michel. *Towards a cognitive approach to human-machine cooperation in dynamic situations.* s.l.: International Journal of Human-Computer Studies, 2001. Vol. 54.

[7] Parasuraman, Raja, Sheridan, Thomas B and Wickens, Christopher D. *A Model for types and levels of humans interaction with automation.* s.l.: Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on, 2000. Vol. 30.

[8] Leeuwen, Peter van, et al. *Effects of concurrent continuous visual feedback on learning the lane keeping task.* s.l.: Proceedings of the Sixth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, 2011.

[9] Sheridan, Thomas B. and Verplank, William L. *Human and Computer Control of Undersea Teleoperators*. s.l.: Massachusetts Institute of Technology Cambridge Man-Machine Systems Lab, 1978.

[10] Flemisch, Frank, et al. *Cooperative Control and active interfaces for vehicle assisstance and automation.* s.l.: FISITA World automotive Congress, 2008.

[11] Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems. s.l.: SAE International, 2014.

[12] Gasser, Tom M. and Westhoff, Daniel. *BASt-study: Definitions of Automation and Legal Issues in Germany.* s.l.: 2012 Road Vehicle Automation Workshop, July 25, 2012.

[13] *Preliminary Statement of Policy Concerning Automated Vehicles.* s.l.: Nationam Highway Traffic Safety Administration, May 30, 2013.

[14] Flemisch, Frank, et al. Automation Spectrum, inner/outer compatibility and other potentially usefull human factors concepts for assisstance and automation. s.l.: Human Factors for assisstance and automation, 2008.

[15] Flemisch, Frank O., et al. *The H-Metaphor as a Guideline for Vehicle Automation and Interaction.* s.l.: NASA Center for AeroSpace Information, 2003.

[16] Abbink, David A. *Neuromuscular analysis of haptic gas pedal feedback during car following.* s.l.: Faculty of Mechanical Maritime and Materials Engineering, Delf University of Technology, 2006.

[17] Winter, Joost C.F. de, et al. *A two-dimensional weighting function for a driver assistance system.* s.l.: Systems, Man, and Cybernetics, Part B: Cybernetics IEEE Transactions on, 2008. Vol. 38.

[18] Mulder, Mark, Abbink, David A. and Boer, Erwin R. *The effect of haptic guidance on curve negotiation behavior of young, experienced drivers.* s.l.: Systems, Man and Cybernetics, 2008 SMC 2008 IEEE International Conference on, 2008.

[19] Abbink, David A., Mulder, Mark and Boer, Erwin R. *Haptic shared control: smoothly shifting control authority?* s.l.: Cognition, Technology & Work, 2012.

[20] Crespo, Laura Marchal, et al. The effect of haptic guidance, aging, and initial skill level on motor learning of a steering task. s.l.: Experimental Brain Research, 2010. Vol. 201.

[21] Zhang, Yu. Visual and Cognitive Distraction Effects on Driver Behavior and an Approach to Distraction State Classification. Raleigh, North Carolina: North Carolina State University, 2011.

[22] Owsley, Cynthia and Jr., Gerald McGwin. *Vision ans Drivng.* s.l.: Vision Research, 2010. Vol. 50.

[23] Boverie, S., Cour, M and Le Gall, JY. *Adapted Human Machine Interaction concept for Driver Assistance Systems DrivEasy.* Milano: 18th IFAC World Congress, 2011.

[24] Flemisch, Franck, et al. *Towards Highly Automated Driving: Intermediate report on the HAVEit-Joint System.* Brussels: 3rd European Road Transport Research Arena, Tra2010, 2010.

[25] Vanholme, Benoit. Highly Automated Driving on Highways based on Legal Safety, PhD Thesis. 2012.

[26] Hesse, Tobias, et al. *Towards user-centred development of integrated information, warning, and intervention strategies for multiple ADAS in the EU project interactive.* s.l.: Universal Access in Human-Computer Interaction. Context Diversity, 2011.

[27] *D24.1 -Vehicle Control Solutions-, SP2.* s.l.: DESERVE project, 2013. Deliverable.

[28] D44.1 -*Automated Functions Solution Design*-, SP4. s.l.: DESERVE project, 2013. Deliverable.

[29] Adams, Lisa D. *Review of the literature on obstacle avoidance maneuvers: braking versus steering.* s.l.: Univ. Michigan Transp. Res. Inst., Ann Arbor, MI, Tech. Rep. UMTRI-94-19, 1994.

[30] Young, Kristie, John D. Lee, and Michael A. Regan, eds. Driver distraction: Theory, effects, and mitigation. CRC Press, 2008.

[31] Walker Smith, B. *Automated Vehicles Are Probably Legal in the United States,* 1 Tex. A&M L. Rev. 411, 2014.

[32] Trimble, Tammy E., Richard Bishop, Justin F. Morgan, and Myra Blanco. *Human factors evaluation of level 2 and level 3 automated driving concepts: Past research, state of automation technology, and emerging system concepts*. No. DOT HS 812 043. 2014.

[33] Anderson, James M., Kalra Nidhi, Karlyn D. Stanley, Paul Sorensen, Constantine Samaras, and Oluwatobi A. Oluwatola. *Autonomous vehicle technology: A guide for policymakers*. Rand Corporation, 2014.

[34] D32.1 -*General Driving Monitoring module definition SoA*-, SP3 s.l.: DESERVE project, 2013 Deliverable.

[35] Beiker, S. and Calo, R. *Legal aspects of autonomous driving.* Santa Clara L. Rev. 52 (2012): 1145.

[36] J. van Dijke and M. van Schijndel, *Citymobil, advanced transport for the urban environment: Update,* Transportation Research Record: Journal of the Transportation Research Board, no. 2324, pp. 29–36, 2012.

[37] D24.4 -*Generic ADAS Control*-, SP2 s.l.: DESERVE project, 2013 Deliverable.

[38] Perez, J. M., David Gonzalez, Fawzi Nashashibi, Gwenael Dunand, Fabio Tango, Nereo Pallaro, and Andre Rolfsmeier. "Development and design of a platform for arbitration and sharing control applications." In Embedded Computer Systems: Architectures, Modeling, and Simulation (SAMOS XIV), 2014 International Conference on, pp. 322–328. IEEE, 2014.